Computational Imaginaries: Some Final Remarks on Leibniz, Llull and Rethinking the History of Calculating Machines

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Leibniz sat gingerly on the edge of the bed, and opened the box.
—Neil Stephenson, 2004

Where do computers come from? How are historical accounts enlisted in the service of different ways of doing and thinking about computing? In this chapter I examine the role and reception of "combinatorial" ideas of Gottfried Leibniz, Ramon Llull, and associated actors in histories and imaginaries of computing. Leibniz is accorded a notable role in various contemporary histories of computation, by practitioners and researchers alike. Although it is questionable the extent to which one can make the case for a direct, unbroken, and material line between his calculating machines and the devices and practices of modern digital computing, nevertheless he is considered to have a significant influence on ideas about computation and visions of computational reason.

As Norbert Wiener writes in his seminal 1948 work *Cybernetics: Or Control and Communication in the Animal and the Machine*: "if I were to choose a patron saint for cybernetics out of the history of science, I should have to choose Leibniz." [1] Scientist and inventor Stephen Wolfram credits Leibniz with anticipating contemporary projects by "imagining a whole architecture for how knowledge would [...] be made computational," suggesting that "many aspects of Leibniz's core vision are finally coming to fruition, albeit in ways he could never have imagined." [2] Other recent writers and commentators describe Leibniz as the "godfather of the modern algorithm" [3] and the "man who envisioned the systems and machines that would define the digital revolution" and "paved the way for the information age." [4] This role has spilled over from history into fiction. Science fiction writer Neal Stephenson dramatizes Leibniz's role in the emergence of computation in his novel *Quicksilver*, which provides the backstory for his 1999 *Cryptonomicon*, blending historical and fictional accounts of computation and cryptography.

What are the implications of the invocation and connection of these figures to contemporary computing practices? What kinds of perspectives are generated, what are we led to attend to, and what is left out? The work of Leibniz and Llull may be considered in relation to contemporary "computational imaginaries." It is important to note that the notion of "imaginaries" relates not only to what people *say* and *think*, but also what they *do* (including, for example, how they

[Epigraph]
Neil Stephenson, *Quicksilver* (London: Arrow Books, 2004), 269.

[1] Norbert Wiener, *Cybernetics: Or Control and Communication in the Animal and the Machine* (Cambridge, MA: The MIT Press, 1985), 12.

[2] Stephen Wolfram, "Dropping In on Gottfried Leibniz," *Stephen Wolfram Blog, May 14, 2013, available at:* http://blog.stephenwolfram.com/2013/05/dropping-in-on-gottfried-leibniz/2013.

[3] Christopher Steiner, *Automate This: How Algorithms Took Over Our Markets, Our Jobs, and the World* (London: Penguin, 2012), 57.

[4] Dan Falk, "The Philosopher Who Helped Create the Information Age," *Slate, November 14, 2016, retrieved from http://www.slate.com/articles/technology/future_tense/2016/11/the_18th_century_philosopher_who_helped_create_the_information_age.html.*

associate and their material practices). Recent research has explored how the notion of "social imaginaries" can be used to study how communities assemble around shared concerns with technical infrastructures and practices. [5] Sheila Jasanoff suggests that the notion of "sociotechnical imaginaries" may be understood as "collectively held and performed visions of desirable futures" drawing on a combination of science and technology studies and social and political theory. [6]

The reception of Leibniz's vast and heterogeneous corpus has been conspicuously slow and uneven. Only a comparatively small portion of his many writings were published during his lifetime, and it would not be until the mid-eighteenth century when more substantive collections of his work began to be published. [7] Different aspects of his work have been mobilized and positioned as important in relation to different aspects of computing. Some of these aspects are illustrated below, as highlighted in texts by Wiener and Wolfram that relate Leibniz's work to cybernetics and modern computing. It is worth noting that such passages reflect imaginaries about Leibniz and the significance of his work as well as imaginaries about computing. [8]

Theme	Wiener, 1985	Wolfram, 2013
Intellectual breadth and connecting work in different fields	"full command of all of the intellectual activity of his day" (2)	"many seemingly disparate and unrelated things"; "systematization and formalization of knowledge"
Mathematical notation	"mathematical notation" (12)	Examples of mathematical notation for infinite series, continued fractions and calculus; "the effort he put into notation, and the clarity of reasoning about mathematical structures and processes that it brought".
Logic	"calculus of reasoning" (12); "mathematical logic" (12)	"logic of invention"
Mechanization of thought	"mechanization of processes of thought" (12)	"the notion that computation is in a sense mechanical"
Universal language (*characteristica universalis*)	"universal symbolism" (12)	"alphabet of human thought"; "decomposing ideas into simple components"; "*ars characteristica*"; "formal, symbolic, representations for a wide range of different kinds of things"
Conceptualizing computation	"calculus ratiocinator" (12, 125); elsewhere he writes "the general idea of a computing machine is nothing but a mechanization of Leibniz's *calculus ratiocinator*" (Wiener, 1948: 214)	"a core intellectual direction that is curiously close to the modern computational one"

Calculating machines	"construction of computing machines in the metal" (12)	"resolved to build an actual mechanical calculator for doing arithmetic"
Monads (and establishing simplest entities of which more complex entities are comprised)	"monads" (41, 58)	"With binary, Leibniz was in a sense seeking the simplest possible underlying structure. And no doubt he was doing something similar when he talked about what he called 'monads'."

Relations of Leibniz' work to cybernetics and computing

Perhaps the most emblematic (although arguably not the most original) of Leibniz's contribution towards modern computing are his various prototypes of calculating machines. Though most of them were lost, one of these machines was found discarded in the corner of the attic by workmen in the course of repairing a leaking roof at the University of Göttingen in 1879. With its cylinders of polished brass and oaken handles, the machine, which Leibniz had dubbed "*Instrumentum Arithmeticum*," was one of a string of mechanical calculators innovating on the work of the French philosopher Blaise Pascal. Supported by a network of professors, preachers, and friends, and developed with the technical assistance of a series of itinerant and precariously employed clockmakers, mechanics, artisans, and a butler — Leibniz's machine aspired to provide less than even the most basic of today's calculators: modestly expanding the repertoire of operations from addition and subtraction to include multiplication and division. [9]

Three centuries before Douglas Engelbart's "Mother of All Demos" received a standing ovation in 1968, Leibniz's machine faltered through live demonstrations in London and Paris. It suffered from a series of financial setbacks and technical issues, and cost a small fortune to construct. The Royal Society invited him to come back once it was fully operational. There is some speculation that — despite Leibniz's rhetoric in letters and publications — it is possible that the machine never actually worked as it was supposed to. [10] Nevertheless, it exercised a powerful grip on the imagination of later technicians and was cited as an influence on the work of generations to come. Leibniz's machine became part of textbooks and industry narratives about the development of

[5] Christopher Kelty, "Geeks, Social Imaginaries, and Recursive Publics," *Cultural Anthropology* 20, 2 (2005): 185–214, available at https://doi.org/10.1525/can.2005.20.2.185; Kelty, *Two Bits: The Cultural Significance of Free Software: The Cultural Significance of Free Software and the Internet* (Durham, NC: Duke University Press, 2008).

[6] Sheila Jasanoff, "Future Imperfect: Science, Technology, and the Imaginations of Modernity," in *Dreamscapes of Modernity: Sociotechnical Imaginaries and the Fabrication of Power*, ed. Sheila Jasanoff and Sang-Hyun Kim (Chicago: University of Chicago Press, 2015), 19.

[7] Catherine Wilson, "The Reception of Leibniz in the Eighteenth Century," in *The Cambridge Companion to Leibniz, ed. Nicholas Jolley* (Cambridge: Cambridge University Press, 1995), 442–70.

[8] I am grateful to Bernard Dionysius Geoghegan for conversations in which he suggested clarifying this point, particularly in relation to recent scholarship on Norbert Wiener and histories of cybernetics.

[9] Cf. Florin-Stefan Morar, "Reinventing Machines: The Transmission History of the Leibniz Calculator," *The British Journal for the History of Science* 48, 1 (2015): 123–46.

[10] Ibid., 18.

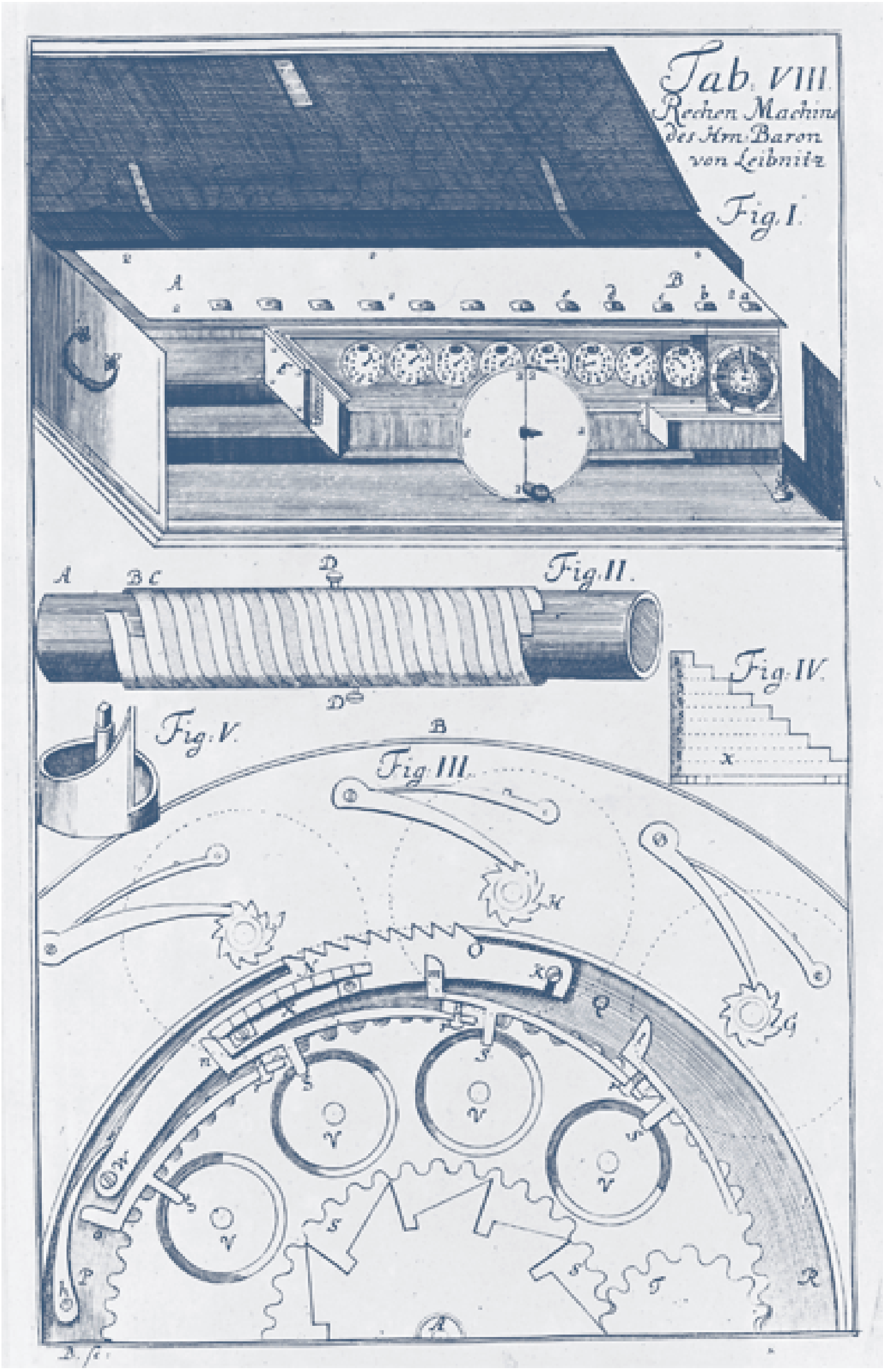

Fig. 1
Details of the mechanisms of the Leibniz calculator, illustration from Jacob Leupold, *Theatrum Arithmetico-Geometricum, Das ist: Schau-Platz der Rechen- und Meß-Kunst [...]* (Leipzig, 1725), tab. 8

computation (see fig. 1). IBM included a replica of one of these machines in their "Antique Attic" contending that it is an important influence on "many later calculating systems." [11]

Leibniz left an extensive scientific and technological legacy that extended well beyond his prototype calculating machines — including contributions towards the modern binary number system as well as integral and differential calculus. But he also articulated a broader computational imaginary which connected these various projects, which sought to explore the analytical and generative possibilities of rendering the world *computable*. Leibniz's interest in this area can be traced back to his 1666 *Dissertatio de arte combinatoria* — an extended version of his doctoral dissertation in which he explores what was known as the "art of combinations" (or "combinatorial art"), which would enable its practitioners to generate novel ideas and inventions, as well as to analyze and break down complex and difficult ideas into more simple elements. He sought to demonstrate the widespread applicability of this art to advance understanding of logic, law, theology, physics, and music.

Leibniz's curiosity around this topic was sparked by a group called the "Herborn Encyclopaedists" through whom he became acquainted with the works of the Majorcan philosopher, logician, and mystical thinker Ramon Llull. [12] Llull's *Ars magna* (or "Ultimate General Art") from 1308 outlines a form of analysis and argumentation based on working with different permutations of fundamental attributes.

Llull sought to create a universal tool for helping to convert people to the Christian faith through logical argumentation. He proposed eighteen fundamental general principles (Goodness, Greatness, Eternity, Power, Wisdom, Will, Virtue, Truth, Glory, Difference, Concordance, Contrariety, Beginning, Middle, End, Majority, Equality, and Minority), accompanied by a set of definitions, rules, and figures in order to guide the process of argumentation, which is organized around different permutations of the principles. The Art was to be used to generate and address questions such as "Is eternal goodness concordant?", "What does the difference of eternal concordance consist of?", or "Can goodness be great without concordance?".

Llull thought that the Art could be used to "banish all erroneous opinions" and to arrive at "true intellectual certitude removed from any doubt." [13] Llull drew in turn on the medieval Arabic *zairja*, described by historian Ibn Khaldūn as "a branch of the science of letter magic [...] the technique of finding out answers from questions by means of connections existing between the letters

[11] IBM, "Leibniz Calculating Machine (Replica)," IBM.com, n. d., available at: https://www-03.ibm.com/ibm/history/exhibits/attic3/attic3_037.html.

[12] Cf. Umberto Eco, *The Search for the Perfect Language*, trans. J. Fentress (Oxford: Blackwell, 1995); John R. Welch, "Llull and Leibniz: The Logic of Discovery," *Catalan Review* 4 (1990): 75–83; Ana Maróstica, "Ars Combinatoria and Time: Llull, Leibniz and Peirce," *Studia Lulliana* 32, 2 (1992): 105–34; Leroy E. Loemker, "Leibniz and the Herborn Encyclopedists," in *The Philosophy of Leibniz and the Modern World*, ed. Ivor Leclerc (Nashville: Vanderbilt University Press, 1973); Olga Pombo "Three Roots for Leibniz's Contribution to the Computational Conception of Reason," in *Programs, Proofs, Processes*, ed. Fernando Ferreira, Benedikt Löwe, Elvira Mayordomo, and Luís Mendes Gomes (Berlin: Springer, 2010), 352–61; Sara L. Uckelman, "Computing with Concepts, Computing with Numbers: Llull, Leibniz, and Boole," in Ferreira et al. (ed.), *Programs, Proofs, Processes*, 427–37.

[13] Ramon Llull, *Ars Generalis Ultima*, trans. Y. Dambergs, 2003, retrieved from: http://lullianarts.narpan.net/Ars-Magna/1-2-3-4.htm.

of the expressions used in the question." [14] The *zairja* was an algorithmic process for calculating truth on the basis of a finite number of elements. Its practitioners would give advice or make predictions on the basis of interpretations of strings of letters resulting from a calculation. Llull's experimentation channeled this procedural conception of reasoning, and was drawn upon by the intellectual milieu in which Leibniz developed his early ideas.

While critical towards the details of Llull's proposed categories and procedures, Leibniz was taken with his overarching vision of the combinatorial Art. Leibniz drew two key aspirations from Llull's work: the idea of fundamental conceptual elements, and the idea of a method through which to combine and calculate with them. The former enables us to reduce more complex ideas down simpler ones, or an "alphabet of human thoughts." For "everything which exists or which can be thought," Leibniz wrote, "must be compounded of parts." [15] The latter enable us to reason with these elements precisely and without error, as well as generate new insights and ideas. Just as all words in a language could be represented by the comparatively small number of letters in an alphabet, so the whole world of nature and thought could be considered in terms of a number of fundamental elements—which he sought to derive through what he called the *characteristica universalis*, or universal language. The combinatorial art would not only facilitate such analysis, but would also provide means to compose new ideas, entities, inventions, and worlds.

Leibniz spared no modesty in promoting the Art and the various initiatives associated with it for which he hoped to raise funds from prospective patrons. He presented his project as being the world's most powerful instrument, an end to all argument, one of humanity's most wonderful inventions (fulfilling a timeless dream shared by everyone from the Pythagoreans to the Cartesians); the ultimate source of answers to some of the world's most complex and difficult theological, moral, legal, or scientific questions; and a foolproof means to convert people to Christianity and propagate the faith, amongst other things.

In support of his project he argued that "no man who is not a prophet or a prince can ever undertake anything of greater good to mankind or more fitting for the divine glory" and that "nothing could be proposed that would be more important for the Congregation for the Propagation of the Faith." [16] In a letter to Johann Friedrich from 1679 he described his project of the universal language as "the great instrument of reason, which will carry the forces of the mind further than the microscope has carried those of sight." Later he wrote:

> The only way to rectify our reasonings is to make them as tangible as those of the Mathematicians, so that we can find our error at a glance, and when there are disputes among persons, we can simply say: Let us calculate, without further ado, to see who is right. [17]

[14] Ibn Khaldūn, *The Muqaddimah: An Introduction to History*, vol. 3, trans. Franz Rosenthal (Princeton, NJ: Princeton University Press, 1958), 182.

[15] Gottfried Wilhelm Leibniz, *Philosophical Papers and Letters*, ed. and trans. Leroy E. Loemker (Dordrecht: Kluwer, 1989), 80.

[16] Ibid., 225, 262.

[17] Gottfried Wilhelm Leibniz, *Leibniz: Selections*, ed. and trans. Philip P. Wiener (New York: Scribner, 1951, 51.

Ultimately, he hoped that the combination of a perspicuous thought language of "pure" concepts, combined with formalized processes and methods for reasoning, akin to those used in mathematics, would lead to the mechanization and automation of reasoning. By means of new artificial languages and methods, our ordinary and imperfect ways of reasoning with words and ideas would give way to a formal, symbolic, rule-governed science of reasoning — conceived of as a computational process. Disputes, conflict, and grievances arising from ill-formed opinions, emotional hunches, biases, prejudices, and misunderstandings would give way to consensus, peace, and progress.

Jonathan Swift later parodied the mechanical conception of invention advanced by Llull and Leibniz in *Gulliver's Travels*. In the fictional city of Lagado, the protagonist encounters a device known as "the engine" which is intended by its inventor to enable anyone to "write books in philosophy, poetry, politics, laws, mathematics, and theology, without the least assistance from genius or study." [18] The mechanical combinatorial approach to cultural creation that Swift treated as an absurd caricature became a productive experimental technique for later writers, artists, and musicians — from the permutational works of American composer John Cage, to generative poetic experiments of the French literary group Oulipo, to more recent procedural approaches of digital and software art. [19] Moreover, the mechanization and externalization of reasoning processes exhibited by machine learning technologies and algorithms has not only become socially and culturally productive, but economically lucrative for today's silicon empires.

There are few contenders in the history of philosophy to rival the optimism that Leibniz had for his project as a kind of panacea to solve many of the world's problems. Many of the ideas of his youth never left him. In a 1714 letter, two years before his death, he laments that he was unable to make more progress:

> I should venture to add that if I had been less distracted, or if I were younger or had talented young men to help me, I should still hope to create a kind of spécieuse générale, in which all truths of reason would be reduced to a kind of calculus. At the same time this could be a kind of universal language or writing, though infinitely different from all such languages which have thus far been proposed, for the characters and the words themselves would give directions to reason, and the errors (except those of fact) would be only mistakes in calculation. [20]

As ever more aspects of earthly life are rendered quantifiable, harvested into clouds, funneled into algorithmic engines — leading to what has been called planetary-scale computation" — these dreams of the vast creative and emancipatory

[18] Jonathan Swift, *Gulliver's Travels into Several Remote Nations of the World* (London: George Bell and Sons, 1899), 191–192.

[19] Cf. Johanna Drucker and Bethany Nowviskie, "Speculative Computing: Aesthetic Provocations in Humanities Computing," in *A Companion to Digital Humanities*, ed. Susan Schreibman, Ray Siemens, and John Unsworth (Oxford: Blackwell, 2004), 431–47; M. Beatrice Fazi and Matthew Fuller, "Computational Aesthetics," in *A Companion to Digital Art*, ed. C. Paul (Chichester: John Wiley, 2016), 281–96; Olga Goriunova, *Read_me: Software Art and Cultures Edition 2004* (Aarhus: Digital Aesthetics Research Centre, University of Aarhus, 2004); Janet Zweig, "Ars Combinatoria," *Art Journal* 56, 3 (1997): 20–29, reprinted pp. XX–XX, this volume.

[20] Leibniz quoted in Donald Rutherford, "Philosophy and Language in Leibniz," in Jolley (ed.), *The Cambridge Companion to Leibniz*, 224–69, here 239.

possibilities of procedural reasoning processes endure. [21] The initial trickles of Llull's and Leibniz's arcane combinatorial fantasies have gradually given way to ubiquitous computational technologies, practices, and imaginaries which are interwoven into the fabric of our worlds — the broader consequences of which are still unfolding around us. The objects of their embryonic faith have become the living *a priori* of the digital age — providing the conditions of possibility for our experience and our reflection, our forms of sociality, and our institutions of judgement — regardless of whether the machines do what we think they do or not.

What can we learn by relating these developments to the computational imaginaries of Leibniz and Llull? What do such histories encourage us to attend to, and what do they leave out? Though there are numerous differences and discontinuities, the way in which these histories have been mobilized in relation to modern computing tells us about enduring imaginaries of the possibility and desirability of *computability*. Leibniz's and Llull's ideas are rooted in philosophical, ontological, and theological conceptions of the reducibility of complex phenomena into an array of basic elements, from which the combinatorial arts obtain their power and relevance. This is often portrayed as a project of *discovery* and *uncovering* these elements.

By contrast, we may perhaps consider contemporary practices and devices in terms of their work to *make things computable*. This includes, for example, social, cultural, and political practices of classification [22]; the institutional contexts of information processing [23]; and different forms of systematically underrecognized intellectual and organizational labor involved in computation, such as the neglected role of women. [24] Computation can be considered as *socially and historically situated* and *distributed* accomplishment, which involves an entanglement of human and non-human actors, discursive and material practices. Rather than seeing figures such as Leibniz and Llull as part of the historical credentialing of dominant conceptions and practices, we may reconsider their role in relation to alternative narratives which interrogate and situate imaginaries of universal computability in relation to an array of epistemic cultures and politics, from Majorcan mysticism and medieval Arabic divination, to patronage, wars, and empires. Critical inquiry into imaginaries of computability might also thus contribute to other ways of thinking about making things computable.

[21] Benjamin Bratton, *The Stack: On Software and Sovereignty* (Cambridge, MA: The MIT Press, 2016).

[22] Geoffrey C. Bowker and Susan Leigh Star, *Sorting Things Out: Classification and Its Consequences* (Cambridge, MA: The MIT Press, 2000).

[23] Jon Agar, *The Government Machine: A Revolutionary History of the Computer* (Cambridge, MA: The MIT Press, 2003).

[24] Marie Hicks, *Programmed Inequality: How Britain Discarded Women Technologists and Lost Its Edge in Computing* (Cambridge, MA: The MIT Press, 2017).